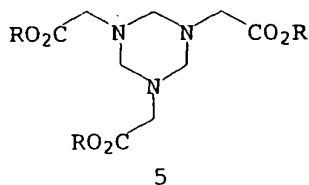


Process for the preparation of N-phosphonomethylglycine

The invention relates to a process for the preparation of
 5 N-phosphonomethylglycine by reacting a hexahydrotriazine compound
 with a triacyl phosphite, and to intermediates for use in this
 process.

N-Phosphonomethylglycine (glyphosate) is a widely employed
 10 nonselective herbicide. A large number of processes for the
 preparation of phosphonomethylglycine are known. One possibility
 of preparing it exists in reacting hexahydrotriazine derivatives
 with phosphorous esters. Thus, US 4,181,800 describes the
 preparation of hexahydrotriazines of the formula:

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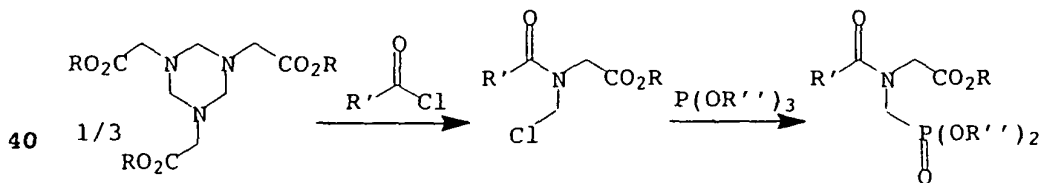


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and US 4,053,505 the reaction of these hexahydrotriazines with
 phosphorous diesters and subsequent hydrolysis of the resulting
 25 product to give phosphonomethylglycine. It has emerged that both
 yield and selectivity favoring the monophosphonated product are
 capable of improvement. Also, phosphorous diesters are very
 expensive.

30 EP-A-104 775 (corresponding to US 4,425,284, US 4,482,504 and
 US 4,535,181) describes the reaction of the above
 hexahydrotriazines with an acyl halide and the subsequent
 phosphonation with a phosphorous triester and hydrolysis to give
 phosphonomethylglycine in accordance with the following equation:

35



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While this process gives relatively good yields of
 45 phosphonomethylglycine, it requires not only the use of the
 expensive phosphorous esters, but additionally the use of
 carbonyl chloride. In addition, the carbonyl chloride might at

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most be recovered in the form of the free acid and then reconverted into the acid chloride in a separate step, which considerably increases the costs of the process. Moreover, the alcohol with which the phosphorous acid is esterified cannot be recycled fully since an equivalent of the corresponding alkyl chloride, which is, moreover, toxicologically unacceptable, is formed during the reaction.

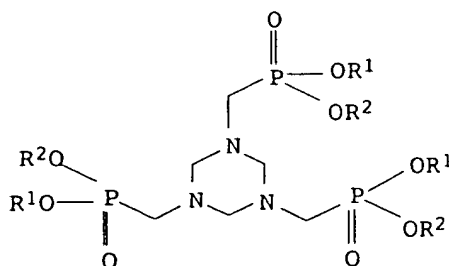
US 4,428,888 (corresponding to EP-A-149 294) describes the reaction of the abovementioned hexahydrotriazine with a phosphorous acid chloride in the presence of a strong anhydrous acid, for example hydrogen chloride, and a C₁-C₆-carboxylic acid, such as acetic acid. In this manner, a large number of undefined by-products are obtained, and these reduce the phosphonomethylglycine yield and necessitate complicated purification of the product.

US 4,442,044 describes the reaction of a hexahydrotriazine of the formula 5 with a phosphorous acid triester to give the corresponding phosphonate compound, which is used as herbicide.

DD-A-141 929 and DD-A-118 435 describe the reaction of an alkali metal salt of the above hexahydrotriazine (R = for example Na) with a phosphorous diester. However, since alkali salts are sparingly soluble, the conversion rate is only low.

US 5,053,529 describes the preparation of phosphonomethylglycine by reacting the above hexahydrotriazines with phosphorous triesters in the presence of titanium tetrachloride, followed by hydrolysis of the product obtained. The use of titanium tetrachloride makes the preparation considerably more expensive. Moreover, the phosphonomethylglycine yields are unsatisfactory.

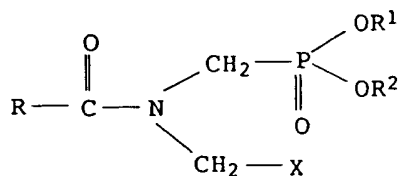
US 4,454,063, US 4,487,724 and US 4,429,124 describe the preparation of phosphonomethylglycine by reacting a compound of the formula



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in which R^1 and R^2 are aromatic or aliphatic groups with $RCOX$
($X = Cl, Br, I$) to give a compound of the formula

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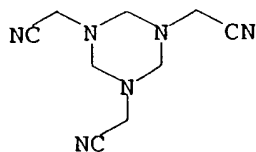


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reaction of this product with a metal cyanide and hydrolysis of
the product obtained. The disadvantages of this method are stated
15 as above in relation to the use of the acid chloride.

Other possible syntheses which have been described are based on
the cyanomethyl-substituted hexahydrotriazine of the formula.

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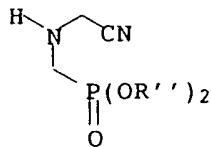


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US 3,923,877 and US 4,008,296 disclose the reaction of this
hexahydrotriazine derivative with a dialkyl phosphonate in the
presence of an acidic catalyst such as hydrogen chloride, a Lewis
30 acid, a carbonyl chloride or a carboxylic anhydride to give a
compound of the formula:

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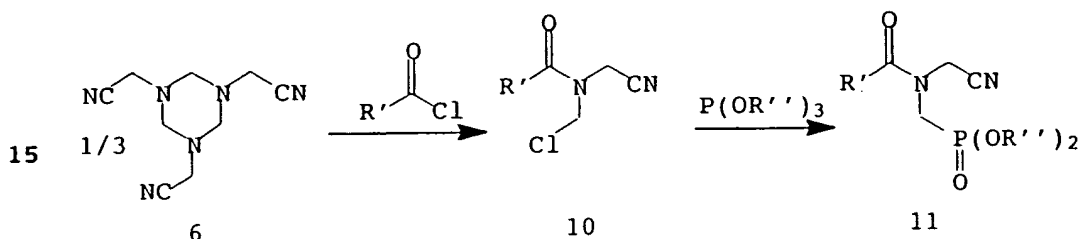
Subsequent hydrolysis yields the phosphonomethylglycine, 8 to 10%
of the diphosphonomethylated product being formed.

US 4,067,719, US 4,083,898, US 4,089,671 and DE-A-2751631
45 describe the reaction of cyanomethyl-substituted
hexahydrotriazine with a diaryl phosphonate in the absence of a
catalyst to give a compound 9 where $R' = \text{aryl}$. This method has

the same disadvantages as described above for the use of the carboxyl-substituted hexahydrotriazine 5.

EP-A-097 522 (corresponding to US 4,476,063 and US 4,534,902)
5 describes the reaction of the hexahydrotriazine 6 with an acyl
halide to give 10, the subsequent phosphonation with a
phosphorous triester or diester to give 11 and finally the
hydrolysis to phosphonomethylglycine as described in the
following equation:

10



20 The disadvantages are the same as for the processes in which the carboxyl-substituted hexahydrotriazine derivatives are used.

Finally, US 4,415,503 describes the reaction of the cyanomethyl-substituted hexahydrotriazine in a manner which is similar to the process described in US 4,428,888. Again, substantial formation of by-products can be observed.

EP 164 923 A describes an improved hydrolysis of a compound of the formula 11.

30

It is an object of the present invention to provide a simple and economical process for the preparation of phosphonomethylglycine in which the phosphomethylglycine is additionally obtained in high purity.

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We have found that this object is achieved by reacting a hexahydrotriazine derivative with a triacyl phosphite and subsequently hydrolyzing the product obtained to give phosphonomethylglycine.

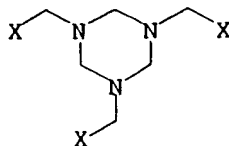
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The present invention therefore relates to a process for the preparation of N-phosphonomethylglycine, wherein

a) a hexahydrotriazine derivative of the formula II

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in which X is CN, COOZ, CONR¹R² or CH₂OY,

10 Y is H or a radical which is readily exchangeable for H,

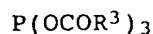
Z is H, an alkali metal, alkaline earth metal, C₁-C₁₈-alkyl or aryl, which is unsubstituted or substituted by C₁-C₄-alkyl, NO₂ or OC₁-C₄-alkyl,

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R¹ and R² can be identical or different and are H or C₁-C₄-alkyl,

is reacted with a triacyl phosphite of the formula III

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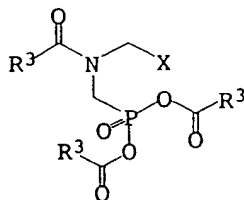


in which the radicals R³, which can be identical or different, are C₁-C₁₈-alkyl or aryl which is unsubstituted or substituted by C₁-C₄-alkyl, NO₂ or OC₁-C₄-alkyl,

25

to give a compound of the formula I

30



35

in which R³ and X have the abovementioned meanings and

b) the compound of the formula I is hydrolyzed, and, if X is
40 CH₂OY, oxidized.

Furthermore, the invention relates to the compounds of the formula I and their preparation in accordance with step a) of the process for the preparation of phosphonomethylglycine.

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6

Alkyl is a linear or branched alkyl chain having preferably 1 to 8 carbon atoms and in particular 1 to 4 carbon atoms. Examples of alkyl are methyl, ethyl, n-propyl, i-propyl, n-butyl, i-butyl, sec-butyl, t-butyl, n-hexyl, 2-ethylhexyl, etc.

5

Aryl is preferably phenyl and naphthyl.

X is preferably CN or COOZ.

10 Z is preferably H, alkali metal or C₁-C₁₈-alkyl.

If Y represents a radical which is readily exchangeable for H, this preferably takes the form of an aliphatic or aromatic acyl radical or C₁-C₆-alkyl group. The aliphatic acyl radical is
15 preferably a C₁-C₆-CO radical, and the aromatic acyl radical preferably takes the form of the benzoyl radical.

R¹ and R² are preferably H.

20 The radical R³ especially preferably takes the form of an aryl radical which can be unsubstituted or substituted as stated above. Especially suitable radicals R³ are phenyl, p-tolyl and p-nitrophenyl.

25 The compounds of the formula II are known and can be prepared in the known manner or analogously to known processes, see, for example, the state of the art mentioned at the outset. For example, an amine X-CH₂-NH₂ can be reacted with a formaldehyde source, such as aqueous formalin solution or paraformaldehyde,
30 for example by dissolving the primary amine in the aqueous formalin solution. The desired hexahydrotriazine can subsequently be obtained by crystallization or evaporation of the water. This process is described in DE-A-2645085 in accordance with US 4,181,800, whose full extent is referred to herewith.

35

The compound of the formula II in which X is CN can be obtained by Strecker synthesis, i.e. by reacting ammonia, hydrocyanic acid and a formaldehyde source. Such a process is described, for example, in US 2,823,222, whose full extent is referred to
40 herewith.

The compounds of the formula III can be prepared by a plurality of processes. A first possibility is to react a salt of a carboxylic acid R³COOH with a phosphorus trihalide, in particular
45 phosphorus trichloride. The carboxylate used is preferably an alkali metal salt or alkaline earth metal salt, in particular the sodium, potassium or calcium salt, or the ammonium salt. This

reaction can be carried out without using a solvent, and the reaction product obtained can be used directly in step (a). However, the process is preferably carried out in an inert organic solvent, in particular in an ether such as dioxane, 5 tetrahydrofuran and the like, a halogenated, in particular a chlorinated or fluorinated, organic solvent such as dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, 1,1,1-trichloroethane, 1,1,2-trichloroethane, 1,1,2,2-tetra-chloroethane, chlorobenzene or 1,2-dichlorobenzene, an aliphatic 10 or aromatic hydrocarbon such as n-octane, toluene, xylene or nitrobenzene. It is preferred to use the same solvent as subsequently in step (a). Especially preferred is the use of a chlorinated hydrocarbon.

15 The salt formed during the reaction, for example sodium chloride when using phosphorus trichloride and the sodium salt of the carboxylic acid employed, can be eliminated after the reaction. If ammonium chloride or another ammonium halide is obtained as the salt, the ammonia employed can be recovered by basifying 20 (pH 11-14) an aqueous solution of the salt with a strong base, for example sodium hydroxide solution, and subsequently stripping the ammonia in the customary manner. The ammonia obtained in this manner can be recirculated after drying, for example by distillation in the liquid or gaseous state, or as aqueous 25 solution, and used for preparing the ammonium salt of the carboxylic acid.

Another possibility of preparing the compounds of the formula III is to react a carboxylic acid R^3COOH with the phosphorus trihalide 30 in the presence of an amine. Amines which are used are, in particular, aliphatic or cycloaliphatic di- or triamines, such as triethylamine, tributylamine, dimethylethylamine or dimethylcyclohexylamine, and pyridine. In general, such a procedure is carried out in an organic solvent. Suitable solvents are stated 35 above in connection with the first possibility for preparation. Dioxane, 1,2-dichloropropane, 1,2-dichloroethane, nitrobenzene or toluene are preferably used. When using a solvent, the amine hydrochloride formed precipitates and can be removed by filtration. If the amine hydrochlorides are treated with a strong 40 base, for example with aqueous sodium hydroxide solution, the amines are set free from the hydrochloride. Volatile amines can then be recovered by distillation or extraction. Nonvolatile amines can be recovered by extraction or, if a two-phase mixture is obtained when the amine is set free, by phase separation. 45 Solid amines can be recovered by filtration. The amines recovered

can be recirculated into the process, if appropriate after drying.

Another possibility of preparing the compounds of the formula III
5 is to react the carboxylic acid R^3COOH with a phosphorus trihalide, in particular phosphorus trichloride, without addition of a base. In this reaction, the hydrogen halide which forms must be removed from the reaction mixture. This can be done in the customary fashion, for example by passing through an inert gas,
10 such as nitrogen. The hydrogen halide which has been set free can then be used for the hydrolysis in step (b) in the form of an aqueous solution.

Step (a) of the process according to the invention can be carried
15 out with or without solvent, for example in the melt. However, it is preferred to use an inert organic solvent, for example a hydrocarbon such as toluene or xylene, an ether such as tetrahydrofuran, dioxane or dibutyl ether, nitrobenzene and the like. It is especially preferred to carry out the process in a
20 halogenated solvent, in particular a chlorinated, preferably a chlorinated and/or fluorinated aliphatic hydrocarbon, such as dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, 1,1,1-trichloroethane, 1,1,2-trichloroethane, 1,1,2,2-tetra-chloroethane, chlorobenzene or 1,2-dichlorobenzene. The reactants
25 are expediently employed in essentially stoichiometric amounts. However, an excess of, for example, up to 10% of one or the other reactant may also be used. In general, the reaction temperature is in the range of $-10^{\circ}C$ to $140^{\circ}C$, preferably in the range of room temperature to $100^{\circ}C$. Only short reaction times are required under
30 these conditions; in general, the reaction is essentially complete after 10 to 30 minutes.

The compounds of the formula I obtained in accordance with step (a) are useful intermediates for preparing phosphonomethyl-
35 glycine. To this end, the compounds of the formula I are hydrolyzed. The hydrolysis can take the form of an acid or alkaline hydrolysis, preferably an acid hydrolysis. Acids which are used are, in particular, inorganic acids such as hydrochloric acid, sulfuric acid or phosphoric acid. Alkaline hydrolysis is
40 generally carried out using an alkali metal hydroxide or alkaline earth metal hydroxide, in particular using sodium hydroxide or potassium hydroxide.

The hydrolysis is expediently carried out with an aqueous acid or
45 base. In general, the aqueous acid or base is added to the reaction mixture obtained in step (a). The hydrolysis can be carried out without solvent or in the presence of an inert

organic solvent which is fully or in part or not miscible with water. The solvent employed in step (a) is preferably used. When using a solvent in step (a), the reaction mixture obtained in step (a) is expediently employed directly, if appropriate after removing, for example by distillation, some of the solvent. As an alternative, the solvent used in step (a) is removed completely and the residue is hydrolyzed. The solvent recovered from the reaction mixture can be reused in the preparation of the compounds of the formula III or in step (a).

10

It is especially preferred to carry out the hydrolysis in a two-phase system (aqueous phase/organic phase). Here, an organic solvent which is miscible in part with water or not miscible with water is used, preferably a hydrocarbon such as toluene or xylene, an ether such as dibutyl ether and in particular a halogenated hydrocarbon such as stated above as solvent for step (a). Hydrolysis is carried out with intimate mixing of the two phases using customary devices, for example stirred reactors, circulating reactors or, preferably, static mixers. After hydrolysis has ended, the phases are separated and processed as described below.

An especially preferred embodiment is a process in which step (a) is carried out in a halogenated solvent, some of the solvent is removed, if appropriate, and the resulting compound of the formula I is hydrolyzed by treating the reaction mixture obtained in step (a) with an aqueous acid or base.

As an alternative, the compound of the formula I can also be hydrolyzed into phosphonomethylglycine by enzymatic means, for example using an esterase or a nitrilase.

The acid or base is used in at least equivalent amounts, but preferably in excess, in particular in an amount of ≥ 2 equivalents.

The temperature at which the hydrolysis is carried out is generally in the range of approximately 10°C to 180°C, preferably 20 to 150°C.

40

If X is CH_2OY , the product obtained after hydrolysis still requires oxidation. The starting compound is, in particular, one in which X is CH_2OH . The oxidation to give phosphonomethylglycine is carried out in the customary manner which is known to the skilled worker, for example by catalytic dehydration with copper catalysis.

10

If X is CH_2OY and Y is an acyl radical, hydrolysis of the product of step a) involves elimination of the acyl radical with formation of the corresponding compound where $\text{X} = \text{CH}_2\text{OH}$. This is oxidized as stated above to give phosphonomethylglycine.

5

If X is CH_2OY and Y is an alkyl radical, ether cleavage normally takes place simultaneously under the conditions of an acid hydrolysis of the product of step a). The compound obtained where $\text{X} = \text{CH}_2\text{OH}$ is oxidized as stated above to give

10 phosphonomethylglycine.

The phosphonomethylglycine obtained when hydrolyzing using an excess of acid or base is dissolved in the aqueous phase. The carboxylic acid R^3COOH is formed directly when hydrolyzing with an
15 excess of acid or, when hydrolyzing with a base, after acidification with a strong acid, preferably to a pH of < 0.5 . The carboxylic acid is then removed in the customary manner, for example by filtration of the carboxylic acid which has precipitated in solid form, distillation or extraction with an
20 organic solvent which is not miscible with the aqueous phase. If hydrolysis is biphasic, the carboxylic acid is present in dissolved form in the organic phase, if appropriate. The carboxylic acid is then removed by separating off the organic phase and, if desired, can be recovered therefrom in the
25 customary manner. It is obtained in high purity and can be recycled without problems for the preparation of the compound of the formula III. The solvent which forms the organic phase can be recirculated and reused in the preparation of the compounds of the formula III or in step (a). In general, however, the solvent
30 is previously subjected to distillation, extraction, filtration and/or stripping in order to remove contaminants such as alcohols, phenols, ammonium salts and/or carboxylic acids which are soluble or insoluble in water.

35 The phosphonomethylglycine can be precipitated by bringing the aqueous phase to a pH in the region of 0.5 to 2.0, in particular 0.8 to 1.5, for example by adding an acid or base, for example HCl , H_2SO_4 or NaOH , KOH , $\text{Ca}(\text{OH})_2$ and obtained in the customary manner, if appropriate by concentrating the aqueous phase and/or
40 addition of a precipitant, for example by filtration. A solvent which is miscible with water, such as methanol, ethanol, isopropanol, acetone and the like, is preferably used as precipitant. The solvents can be recovered from the mother liquor by distillation and reused.

45

Ammonia or ammonium chloride formed during the hydrolysis can be recirculated into the process, if appropriate by basifying the mixture and recovering the ammonia by stripping.

5 If required, the phosphonomethylglycine obtained can be decolorized in the customary manner. This can be done for example by treating it with small amounts of a decolorizing agent, for example oxidants such as perborates or H_2O_2 or adsorbents such as active charcoal. The amount of decolorizing agent depends on the
10 degree of the discoloration and can be determined in a simple manner by the skilled worker. The treatment with the decolorizing agent can be performed at any point after hydrolysis and in the customary manner. It is expedient to add the decolorizing agent before precipitating the phosphonomethylglycine.

15 The process according to the invention, or each step on its own, can be carried out continuously, discontinuously or as a semi-batch process. Reaction vessels which are customary for such purposes are used, such as stirred reactors or tubular reactors,
20 if appropriate with mixing devices arranged upstream or with mixing elements integrated into the tubular reactor.

The process according to the invention is thus distinguished by simple process control and inexpensive feed stocks. Only an
25 inorganic chloride is produced as waste product, and the protective groups, viz. the acetyl radicals of the triacetyl phosphite of the formula III, can be recycled in a simple manner. The process yields phosphonomethylglycine in very short reaction times and high yields of >90% of hexahydrotriazine of the formula
30 II.

The examples which follow illustrate the invention without imposing any limitation.

35 Example 1:

0.2 mol of sodium benzoate are introduced into 50 ml of 1,4-dioxane at room temperature with the exclusion of moisture. 0.0667 mol of phosphorous trichloride are added dropwise, and
40 stirring of the reaction is continued for 20 minutes at 85°C (colorless suspension). 0.0222 mol of the hexahydrotriazine 6 are added, and the reaction is stirred for a further 20 minutes at 85 to 90°C (thin suspension, readily stirrable). The dioxane is subsequently distilled off in vacuo at 40°C. 100 ml of
45 concentrated hydrochloric acid are added to the residue and the

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mixture is refluxed for 4 hours. After cooling, the benzoic acid is filtered off, washed (with a little cold water) and dried.

The combined filtrates are evaporated to dryness. To isolate the
5 phosphonomethylglycine, the residue is taken up in a little water and precipitated by adding cold NaOH to pH = 1.5. Complete precipitation is achieved by adding a little methanol. The phosphonomethylglycine is filtered off and dried.

10 Yield: 10.3 g of phosphonomethylglycine (purity 95.3% according to HPLC), corresponding to 91% yield based on PCl_3 . The crystallization mother liquor still contains 1.8% by weight of phosphonomethylglycine.

15 Example 2:

0.2 mol of sodium benzoate are introduced into 50 ml of 1,4-dioxane at room temperature with the exclusion of moisture. 0.0667 mol of phosphorous trichloride are added dropwise, and
20 stirring of the reaction is continued for 20 minutes at 85°C (colorless suspension). The reaction is filtered with the exclusion of moisture and the residue is washed with a little dioxane. 0.0222 mol of the hexahydrotriazine 6 are added to the filtrate, still with exclusion of moisture, and the reaction is
25 stirred for a further 20 minutes at 85 to 90°C. The dioxane is subsequently distilled off in vacuo at 40°C. 100 ml of concentrated hydrochloric acid are added to the residue and the mixture is refluxed for 4 hours. After cooling, the benzoic acid is filtered off, washed (with a little cold water) and dried.

30

The combined filtrates are evaporated to dryness. To isolate the phosphonomethylglycine, the residue is taken up in a little water and precipitated by adding cold NaOH to pH = 1.5. Complete precipitation is achieved by adding a little methanol. The
35 phosphonomethylglycine is filtered off and dried.

Yield: 10.5 g of phosphonomethylglycine (purity 94.1% according to HPLC), corresponding to 93% yield based on PCl_3 . The crystallization mother liquor still contains 1.9% by weight of
40 phosphonomethylglycine.

Example 3:

A solution of 0.12 mol of triacetyl phosphite in 50 ml of dioxane
45 is added at room temperature to a solution of 0.04 mol of the hexahydrotriazine 6 in 80 ml of dioxane. Stirring of the solution is continued for 2 hours at 100°C. The solvent is subsequently

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distilled off at 40°C, first under atmospheric pressure and then in vacuo. 100 ml of concentrated hydrochloric acid are added to the residue and the reaction is refluxed for 4 hours. The reaction mixture is evaporated to dryness. To isolate the
5 phosphonomethylglycine, the residue is taken up in a little water and precipitated by adding cold NaOH to pH = 1.5. Complete precipitation is achieved by adding a little methanol. The phosphonomethylglycine is filtered off and dried.

10 Yield: 15.4 g of phosphonomethylglycine (purity 98.7% according to HPLC), corresponding to 76% yield based on PCl_3 . The crystallization mother liquor still contains 1.6% by weight of phosphonomethylglycine.

15 Example 4:

284 g of ammonium benzoate in 1000 ml of 1,2-dichloroethane are introduced into a stirred 2-l-flask equipped with a teflon blade mixer and a reflux condenser, and 91.5 g of phosphorus
20 trichloride are added dropwise under a nitrogen atmosphere in the course of 30 minutes. During this, the temperature climbs to a maximum of 36°C. Stirring is subsequently continued for 30 minutes at 25 to 36°C. The mixture is filtered through a pressure filter, and the filter cake is washed twice more with two 500 g portions
25 of dichloroethane under nitrogen (2054 g of filtrate).

The filtrate is introduced at room temperature into a stirred 2-l-flask equipped with a teflon blade mixer and a reflux condenser. The stirred filtrate is heated to 80°C in the course of
30 30 minutes, and stirring is continued for 30 minutes at 80°C. The solution is left to cool and is hydrolyzed directly thereafter.

To this end, the feedstock is metered at 130°C and 8 bar into a tubular reactor (approx. volume 600 ml) with a static mixer
35 arranged upstream (1265 g/h of the dichloroethane solution from the preceding step, 207 g/h 20% strength HCl). The residence time is 30 minutes. The first runnings are discarded. For processing, the resulting two-phase mixture is collected for 60 minutes. The phases are separated at 60°C and the aqueous phase is extracted
40 twice with two 100 g portions of dichloroethane.

The dichloroethane, which is still present in the aqueous phase, is first stripped at 60°C in a round-bottomed flask equipped with a teflon blade stirrer by passing in nitrogen. Then, the pH is
45 brought to 1.0 at 40 to 60°C in the course of 15 minutes, using 50% strength sodium hydroxide solution. Stirring of the resulting suspension is continued for 3 hours at 40°C, the mixture is left

to cool to room temperature, and the product which has precipitated is filtered off with suction and subsequently washed with 150 g of ice-water. The resulting solid is dried for 16 hours at 70°C and 50 mbar.

5

Yield: 54.6 g of phosphonomethylglycine (purity according to HPLC: 96.2%), which corresponds to 80% yield based on PCl_3 . The crystallization mother liquor still contains 2.1% by weight of phosphonomethylglycine.

10

Example 5:

A saturated solution in water is prepared from the ammonium chloride residue of the tribenzoyl phosphite synthesis as described in Example 4. This saturated solution is combined with the mother liquor from the crystallization of the phosphonomethylglycine as described in Example 4 and brought to pH 14 with excess sodium hydroxide solution. Then, ammonia is stripped from the reaction mixture using nitrogen and collected for gas analysis by means of GC (purity 99%). The combined dichloroethane phases from the hydrolysis are dried by distilling off the azeotrope dichloroethane/water. Dry ammonia is passed into the dichloroethane until all of the benzoic acid has been reacted to give ammonium benzoate, and the resulting suspension of ammonium benzoate in 1,2-dichloroethane is returned into the synthetic procedure.

Yield (first recycling): 54.0 g of phosphonomethylglycine (purity 97.0% according to HPLC) corresponds to 79% yield based on PCl_3 .

30

Yield (second recycling): 55.1 g of phosphonomethylglycine (purity 95.5% according to HPLC) corresponds to 81% yield based on PCl_3 .

35 Example 6:

The reaction is carried out as described in Example 4, except that nitrobenzene is used as solvent instead of 1,2-dichloromethane.

40

Yield: 56.2 g of phosphonomethylglycine (purity according to HPLC: 97.4%), which corresponds to 82% yield based on PCl_3 . The crystallization mother liquor still contains 2.0% by weight of phosphonomethylglycine.

45

Example 7:

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The reaction is carried out as described in Example 4, except that 1,2-dichloropropane is used as solvent instead of 1,2-dichloroethane.

5 Yield: 54.0 g of phosphonomethylglycine (purity according to HPLC: 96.92%), which corresponds to 79% yield based on PCl_3 . The crystallization mother liquor still contains 2.1% by weight of phosphonomethylglycine.

10 Example 8:

The reaction is carried out as described in Example 1, except that 1,2-dichloroethane is used as solvent instead of dioxane. The phosphonomethylglycine yield is 75%.

15

Example 9:

The reaction is carried out as described in Example 1, except that toluene is used as solvent instead of dioxane. The
20 phosphonomethylglycine yield is 68%.

Example 10: Preparation of the phosphite from carboxylic acid, amine and PCl_3

25 0.05 mol of phosphorus trichloride in 15 ml of toluene is added dropwise at 0°C to a solution of 0.15 mol of benzoic acid and 0.15 mol of dimethylcyclohexylamine in 90 ml of toluene. Stirring is continued for 15 minutes at 0°C and the mixture is subsequently allowed to come to room temperature. The hydrochloride which has
30 precipitated is filtered through a pressure filter with exclusion of moisture. The tribenzoyl phosphite is characterized via analysis of the filtrate by ^1H NMR and ^{31}P NMR (yield: 99%). If the residue obtained from the filtrate after the toluene has been distilled off is added to 0.15 mol of 10% strength NaOH,
35 dimethylcyclohexylamine can be recovered quantitatively by phase separation followed by extraction with toluene. The solution is subsequently dried by removing the water azeotropically and can be reused.

40 Example 11:

0.2 mol of sodium benzoate are added to 50 ml of 1,4-dioxane at room temperature with exclusion of moisture. 0.0667 mol of phosphorus trichloride is added dropwise and stirring of the
45 mixture is continued for 20 minutes at 85°C (colorless suspension). 0.0222 mol of the hexahydrotriazine 1 ($\text{X}=\text{CN}$) is added, and stirring of the mixture is continued for another

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20 minutes at 85–90°C (thin suspension, readily stirrable). The dioxane is subsequently distilled off in vacuo at 40°C. 100 ml of concentrated hydrochloric acid are added to the residue and the mixture is refluxed for 4 hours. When cold, the benzoic acid is
5 filtered off and washed (a little cold water). The combined filtrates are extracted twice with in each case 30 ml of toluene, evaporated to dryness on a rotary evaporator and rotary-evaporated three more times with ethanol to remove excess hydrochloric acid. The toluene phase is concentrated and the
10 residue is combined with the benzoic acid which has been recovered.

To isolate the phosphonomethylglycine from the residue of the aqueous phase, this may now be taken up in a little water and
15 precipitated cold at pH 1.0 (addition of NaOH). Complete precipitation is achieved by adding a little methanol, which is recovered from the mother liquor by distillation. Yield: 91%.

The benzoic acid which has been recovered (0.2 mol, purity >99%
20 according to HPLC) is dissolved in 0.2 mol of 5% strength NaOH, the water is subsequently distilled off and the residue is dried. The resulting sodium benzoate together with the dioxane which has been recovered is reused in the synthetic procedure.

25 Yield (first recycling): 90%
Yield (second recycling): 84%
Yield (third recycling): 88%.

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